Alternative Earthen Final Covers: A Regulatory Perspective

Bill Albright
Desert Research Institute
University of Nevada

for

State of California

Integrated Waste Management Board
and
Water Resources Control Board

Introduction

- Purpose of final covers
- Regulatory review
- Liner / cover configurations
- AEFC issues: the regulatory perspective
  - Equivalency
  - How AEFCs work
  - Basic hydrology
  - Engineering philosophy
  - Defining the design process

Why Final Covers?

- Physical confinement to control spread of litter
- Control infiltration of precipitation
  - minimize production of leachate
  - minimize production of gas
- Fire control
- Limit rodent and bird contact with the refuse
- Control visual and odor aspects of facility

CALIFORNIA LAW

- Section 20950(a)(2)(A)(1), Title 27 CCR - SWRCB
- "For landfills the goal of closure, including but not limited to the installation of a final cover, is to minimize the infiltration of water into the waste, thereby minimizing the production of leachate and gas."

- Section 21140(a), Title 27 CCR - CIWMB
- "The final cover shall function with minimum maintenance and provide waste containment to protect public health and safety by controlling, at a minimum, vectors, fire, odor, litter and landfill gas migration. The final cover shall also be compatible with postclosure land use."

- Section 21140(c), Title 27 CCR - CIWMB
- "The EA may require additional thickness, quality, and type of final cover depending on, but not limited to, the following: (1) a need to control gas emissions and fires; (2) the future reuse of the site; and (3) provide access to all areas of the site as needed for inspection of monitoring and control facilities."

ALTERNATIVES?

- Section 21090(a), Title 27 CCR - SWRCB
- "The RWQCB can allow any alternative final cover design that it finds will continue to isolate the waste in the Unit from precipitation and irrigation waters as well as would a final cover built in accordance with applicable prescriptive standards."

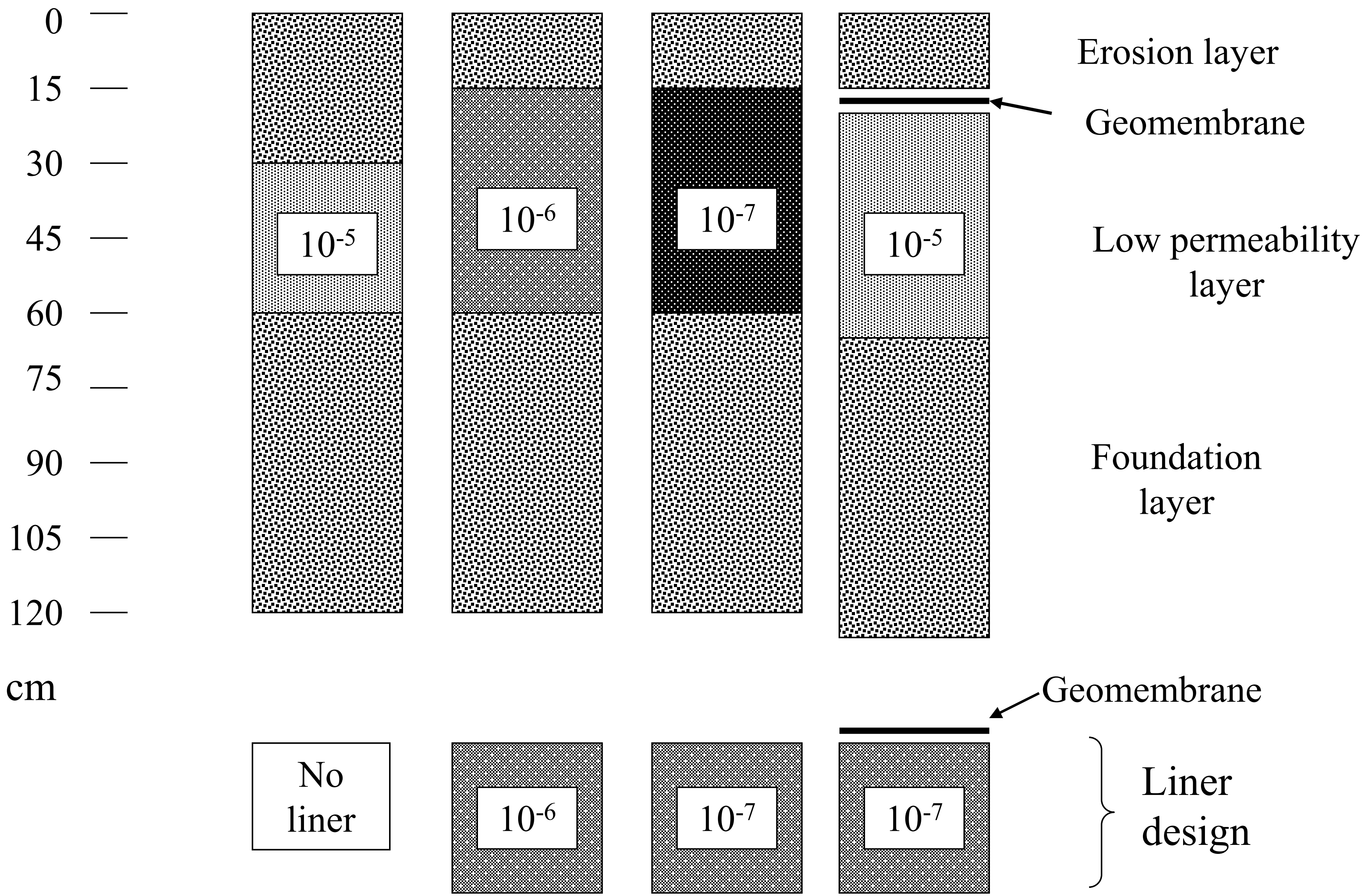
- Section 20950(a)(2)(A)(1), Title 27 CCR - SWRCB
- "For landfills the goal of closure, including but not limited to the installation of a final cover, is to minimize the infiltration of water into the waste, thereby minimizing the production of leachate and gas."

- Section 21140(b), Title 27 CCR - CIWMB
- "Alternative final cover designs shall meet the requirements of part (a) [i.e., control vectors, fire, odor, litter and landfill gas migration] and shall be approved by the enforcement agency."

Prescriptive cover depends on liner design

Existing liner design	Prescriptive cover design
No liner	• 30 cm erosion protection layer • 30 cm barrier layer: $K_{sat} \leq 10^{-5}$ cm/sec or $\leq K_{sat}$ of underlying soils, whichever is less • 60 cm foundation
Soil liner $K_{sat} \leq 10^{-6}$ cm/sec	• 15 cm erosion protection layer • 45 cm barrier layer with $K_{sat} \leq 10^{-6}$ cm/sec • 60 cm foundation
Soil liner $K_{sat} \leq 10^{-7}$ cm/sec	• 15 cm erosion protection layer • 45 cm barrier layer with $K_{sat} \leq 10^{-7}$ cm/sec • 60 cm foundation
Composite Liner: Soil layer: $K_{sat} \leq 10^{-7}$ cm/sec Overlain by geomembrane	• 15 cm erosion protection layer • Geomembrane • 45 cm barrier layer with $K_{sat} \leq 10^{-5}$ cm/sec • 60 cm foundation

Liner / prescriptive cover designs



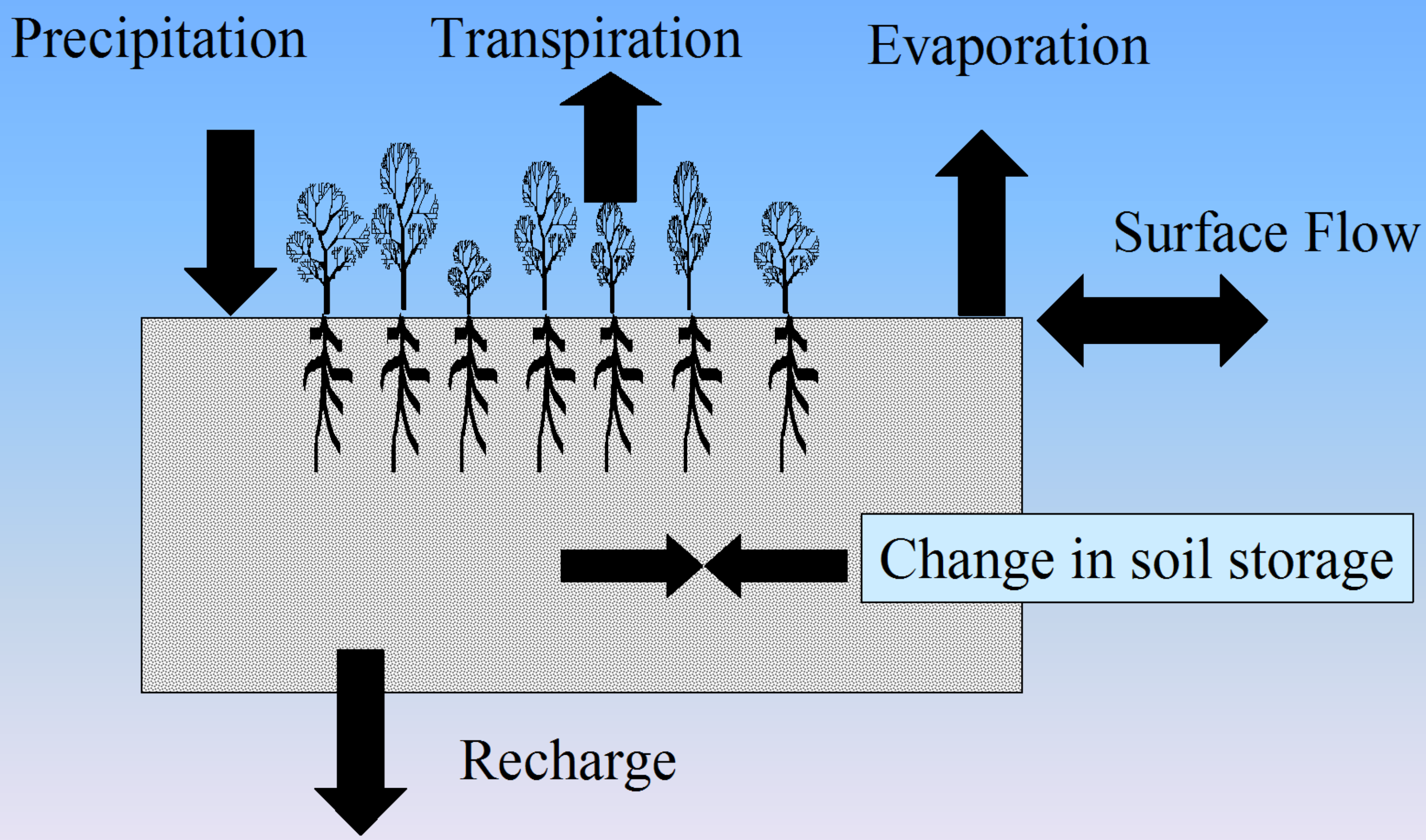
Equivalency

- Equivalent hydrologic performance means percolation from AEFC $\leq$ percolation from prescriptive cover
- Are there data for prescriptive designs?
- Are there data for alternative designs?
- How to determine equivalency?
  - Modeling – which model?
  - Side-by-side field performance

How do AEFCs work?

- Store and release
- Exploit two natural functions:
  - Water storage capacity of soil (sponge)
  - Solar powered pumps (plants)
- Can be enhanced by features such as capillary barriers

Hydrologic Components of Covers



Engineering Philosophy

- Prescriptive covers
  - Engineering by regulation
  - Can be applied anywhere
  - Based on material parameters
  - Performance not specified (not known)
- Alternative covers – descriptive process
  - Site specific
  - Determine performance criterion
  - Interdisciplinary site characterization (soils, plants, climate)
  - Design and predict performance

Break

- Discussion
  - Definition of equivalency
  - Cover/liner combinations
  - Shift from prescriptive design to descriptive process: responsibilities of regulatory community

Defining the Design Process

1) Laboratory analysis of soil

    Determine water storage capacity of soil (3)

    Hydrologic parameters (4)

2) Determine design precipitation event

    Seasonal for calculating water storage requirements (3)

    High resolution (daily) for numerical simulations (4)

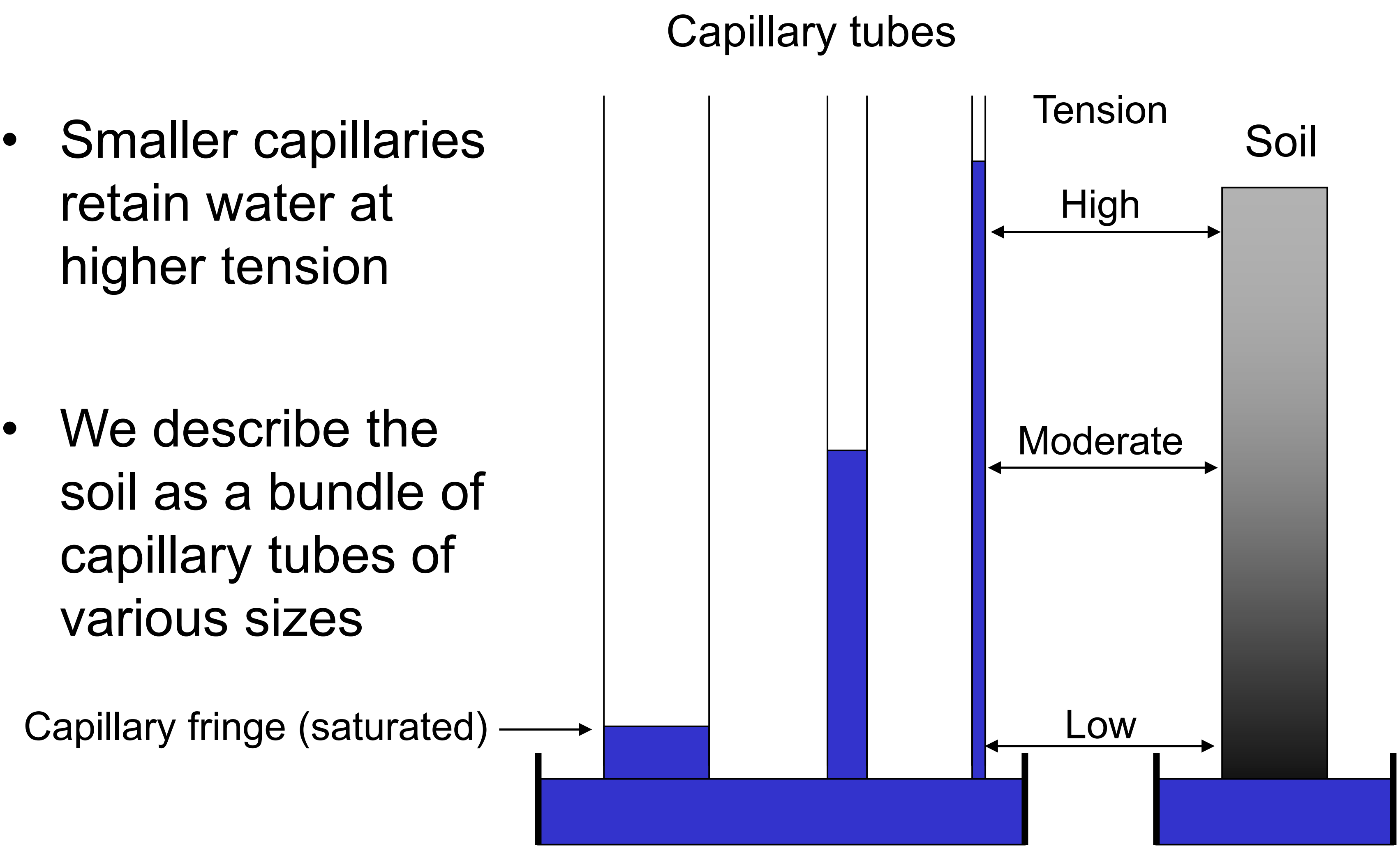
3) Calculate required depth of soil for water storage layer

4) Numerical simulations to incorporate environmental stresses

Brief Diversion Into Hydrology and Soil Physics………..

Retention Properties - Concept

- Smaller capillaries retain water at higher tension
- We describe the soil as a bundle of capillary tubes of various sizes



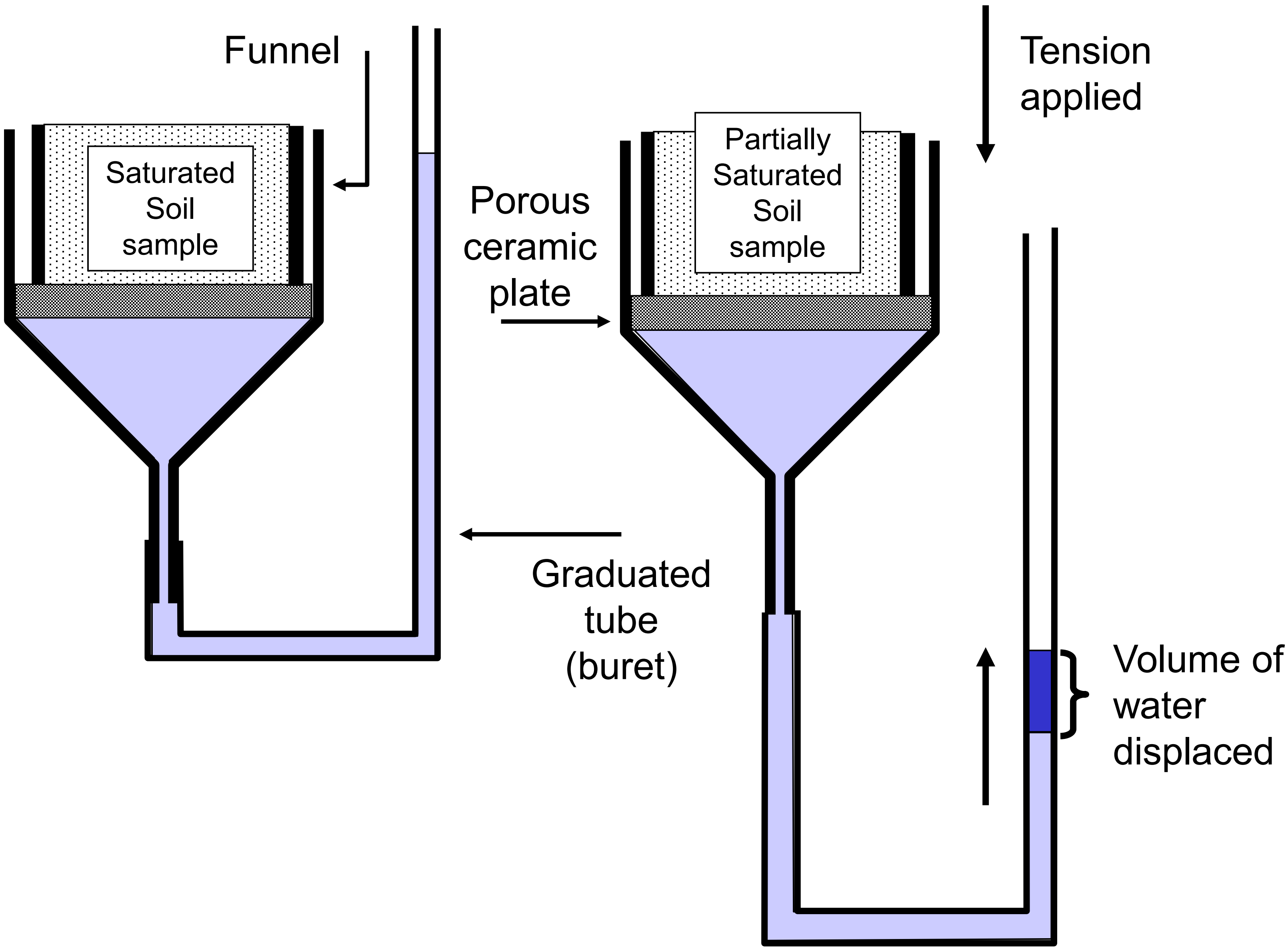
Water storage capacity of soil

- Determined from retention properties
- Retention curve (soil water characteristic curve) is determined from lab data
- Retention curve describes the relationship between water content and matric potential (soil suction, soil water potential energy, etc)
- Available water storage capacity is the difference in water content between field capacity and wilting point

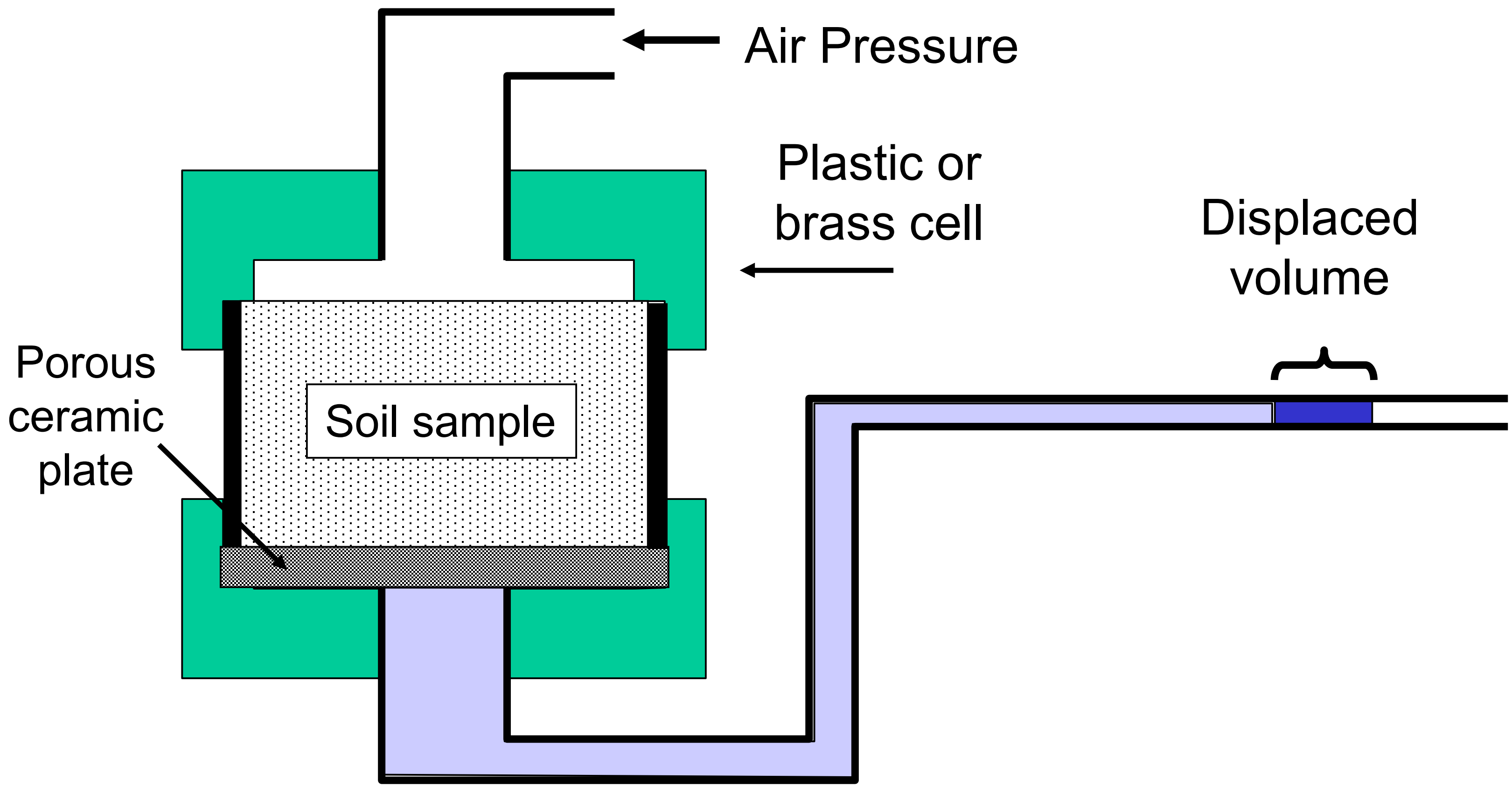
Retention methods

- Hanging column
- Pressure plate apparatus
- Tempe cell apparatus
- Chilled mirror hygrometer

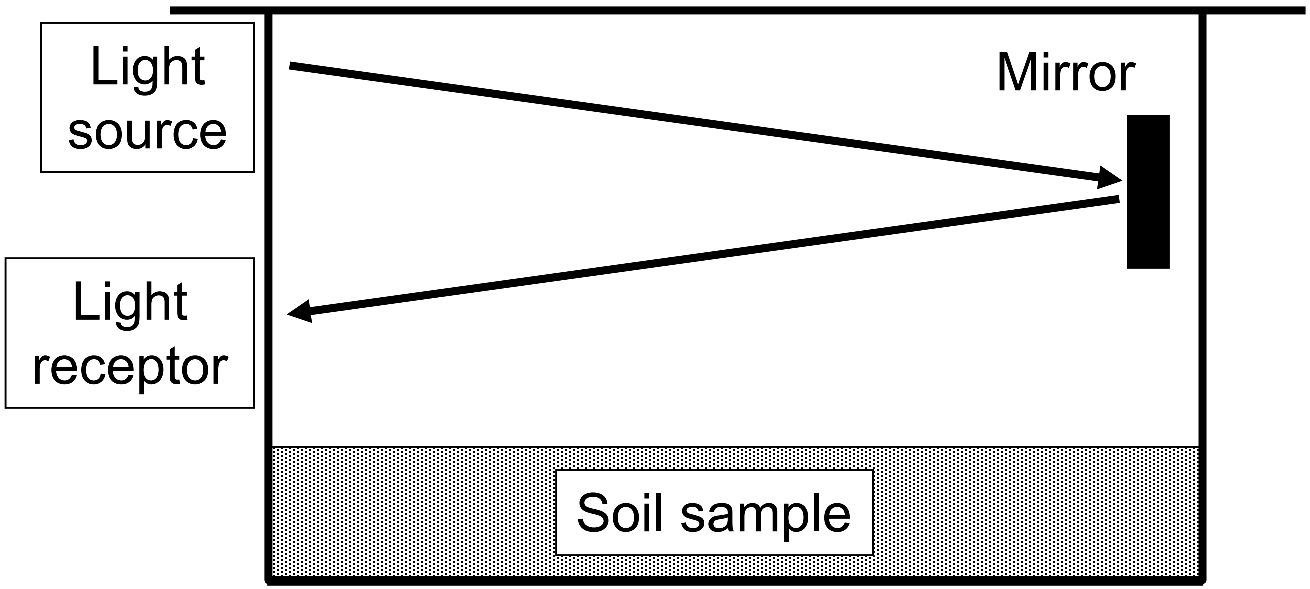
Hanging column



Pressure Cell Apparatus

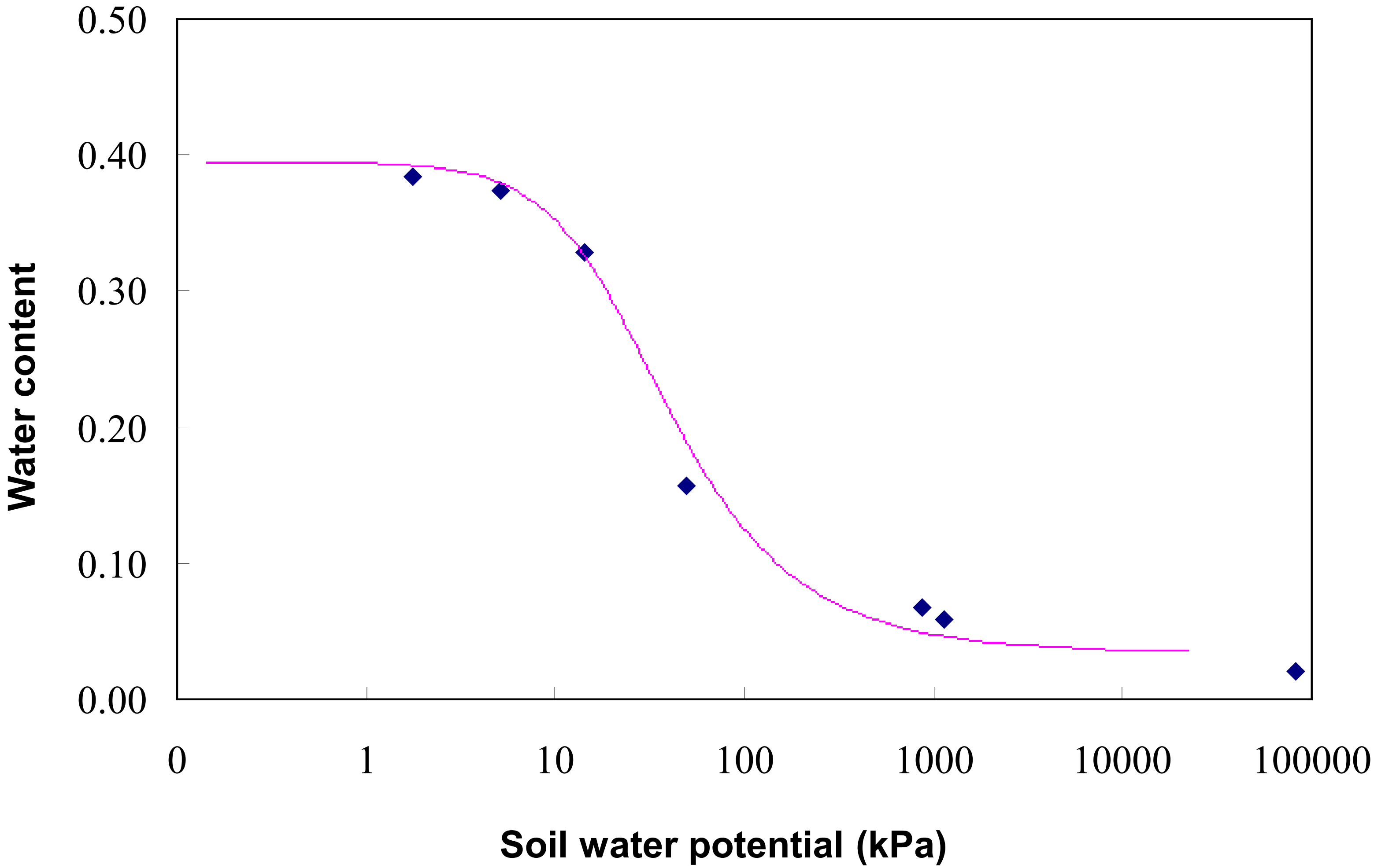


Chilled mirror hygrometer



- Air in chamber equilibrates with soil moisture
- Mirror is cooled to dew point
- Moisture condenses on mirror, scattering light
- Dew point related to soil moisture potential

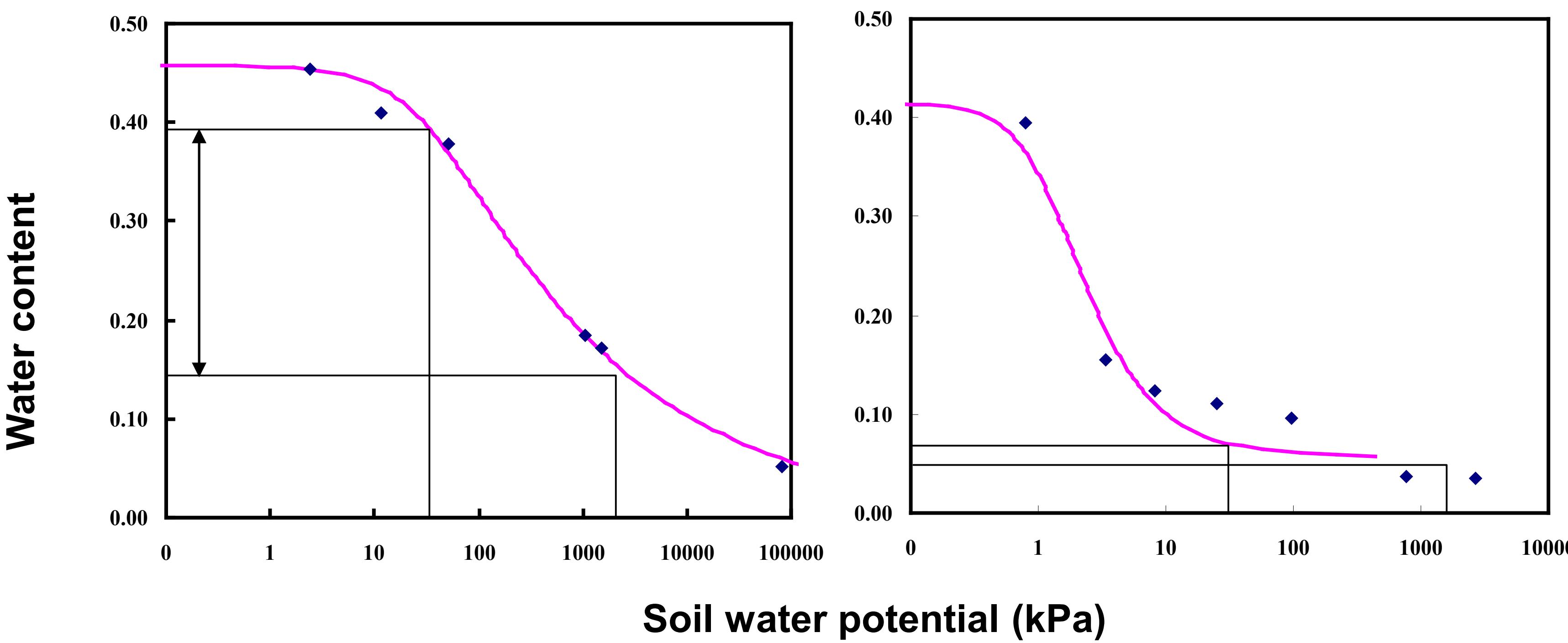
Retention Data & Fitted Curve



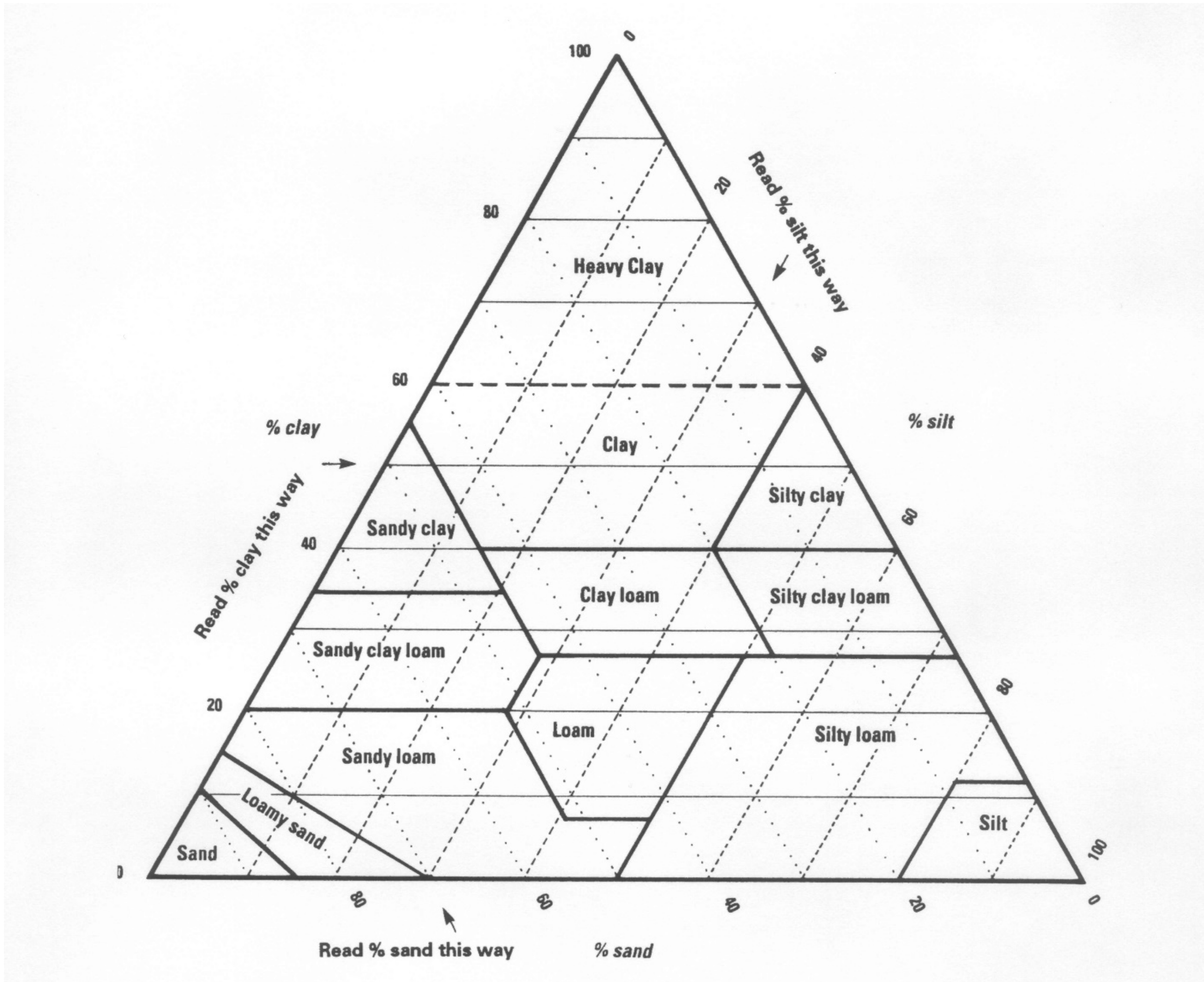
Available water holding capacity

- Field capacity corresponds to ~ 33 kPa
- Wilting point corresponds to ~ 1500 kPa (6500 kPa)
- Water holding capacity is difference in water contents between these 2 points

Units!
1 bar
100 kPa
1020 cm H_2O



Soil Textural Triangle



Important point: it is pore size distribution (not grain size distribution) that determines flow characteristics

Design Precipitation Events

- For use in calculating water storage requirements
- For use in numerical simulations
- Important regulatory decision

Precipitation Data for Calculating Water Storage Requirements

- How much water must be stored…
  - Average
  - X-yr maximum
  - Period of record
- …and for what period of time?
  - Relative timing of precipitation (P) and transpiration (T) very important
  - During storms P > ET
  - Cold winters: T may be ~ 0 for months
  - Mild winters: P and T may coincide

Source of climate data

- Western Regional Climate Center:
  www.wrcc.dri.edu

- Precipitation
- PET
- Temperature

Calculation of required depth of soil for water storage layer

- Input:
  - Water storage capacity of soil (a)
    (meters of water / meter of soil)
  - Storage requirement (b)
    (meters of water)
- Calculate required depth of soil:

$$\frac{b}{a} = \text{meters of soil}$$

Break

- Discussion
  - Retention theory
  - Lab analysis of soil
  - Design precipitation events
  - Calculation of soil layer storage requirements

Numerical simulations (computer models)

- Purpose: to refine design by introducing environmental stress
- Regulatory concerns
  - Which model? HELP, HYDRUS-2D, UNSAT-H, LEACHM, EPIC, SoilCover, ETC-X
  - Input parameters: source?
  - Input data sets: source?
  - Results: how displayed?

Modeling:
the map is not the territory

You have data?

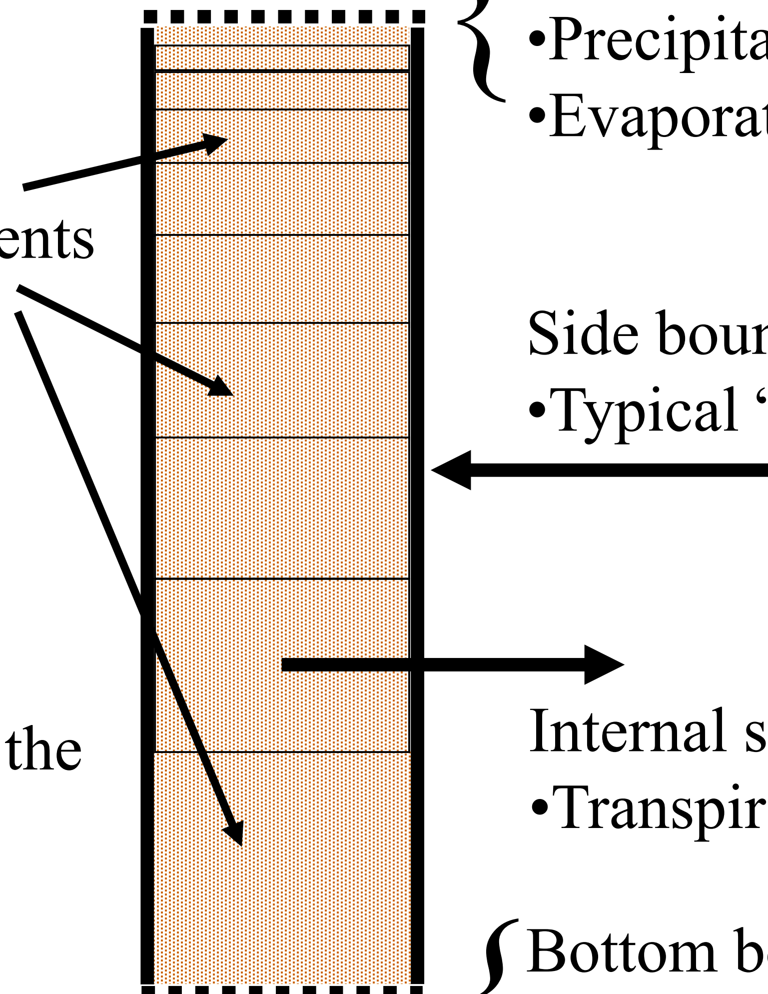
well known, unnamed modeler

personal communication

What’s a model?

Surface boundary condition:
- Precipitation
- Evaporation

(Finite) elements



Side boundary condition:
- Typical “no flux”

Initial conditions:
How wet was the soil at the start of the simulation?

Internal sinks:
- Transpiration (roots)

Bottom boundary condition:
- Typical “free drainage”

…..more diversion:

Unsaturated parameters for modeling

Unsaturated soil parameters for modeling

- Models require value for unsaturated hydraulic conductivity (K_{unsat} or $K\psi$)
- Very difficult, time consuming, and expensive to *measure*
- Can be *estimated* from measured values for K_{sat} and retention properties

An aside to the diversion……
saturated vs unsaturated

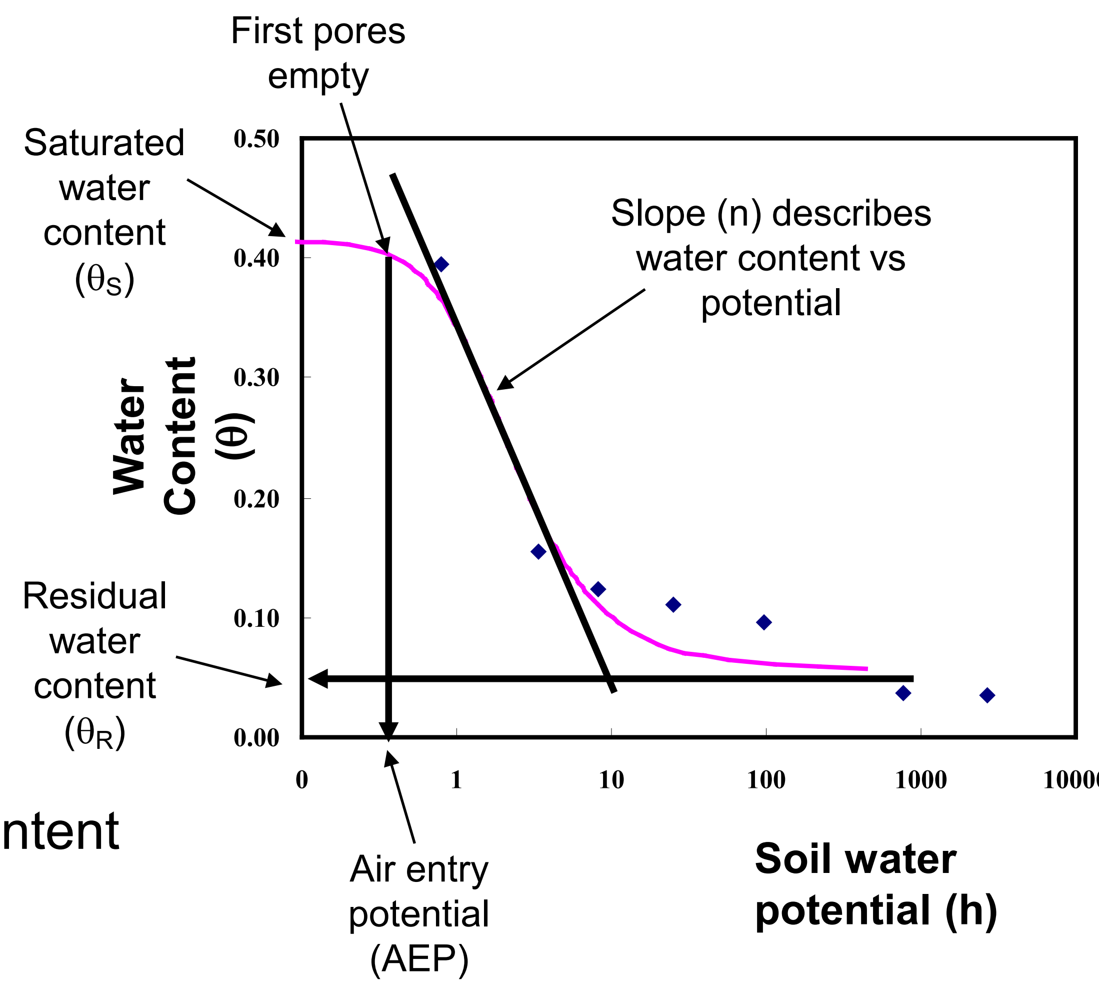
- Below the water table
  - all pore space is filled with water
  - gravity dominates
- Above the water table: unsaturated (vadose) zone
  - varying degrees of air-filled porosity
  - capillary forces quickly dominate

Vadose zone hydrology (cont)

- Conceptual model is flow of water through collection of tubes – some of which may be empty
- Basic physics is Poiseuille's Law for water flow through pipes (relates flow to pipe diameter)
- Mualem combined Poiseuille's Law with various factors to describe flow of water through porous media with pores of various sizes, connected-ness, and tortuosity
- Problem: no connection to lab or field parameters
- van Genuchten described an equation that fits the shape of retention data *and* which provides the link to connect lab data to Mualem's model

Vadose zone hydrology (condensed)

$$\frac{\theta - \theta_R}{\theta_S - \theta_R} = \frac{1}{\left[1 + (\partial h)^n\right]^m}$$



θ = volumetric water content

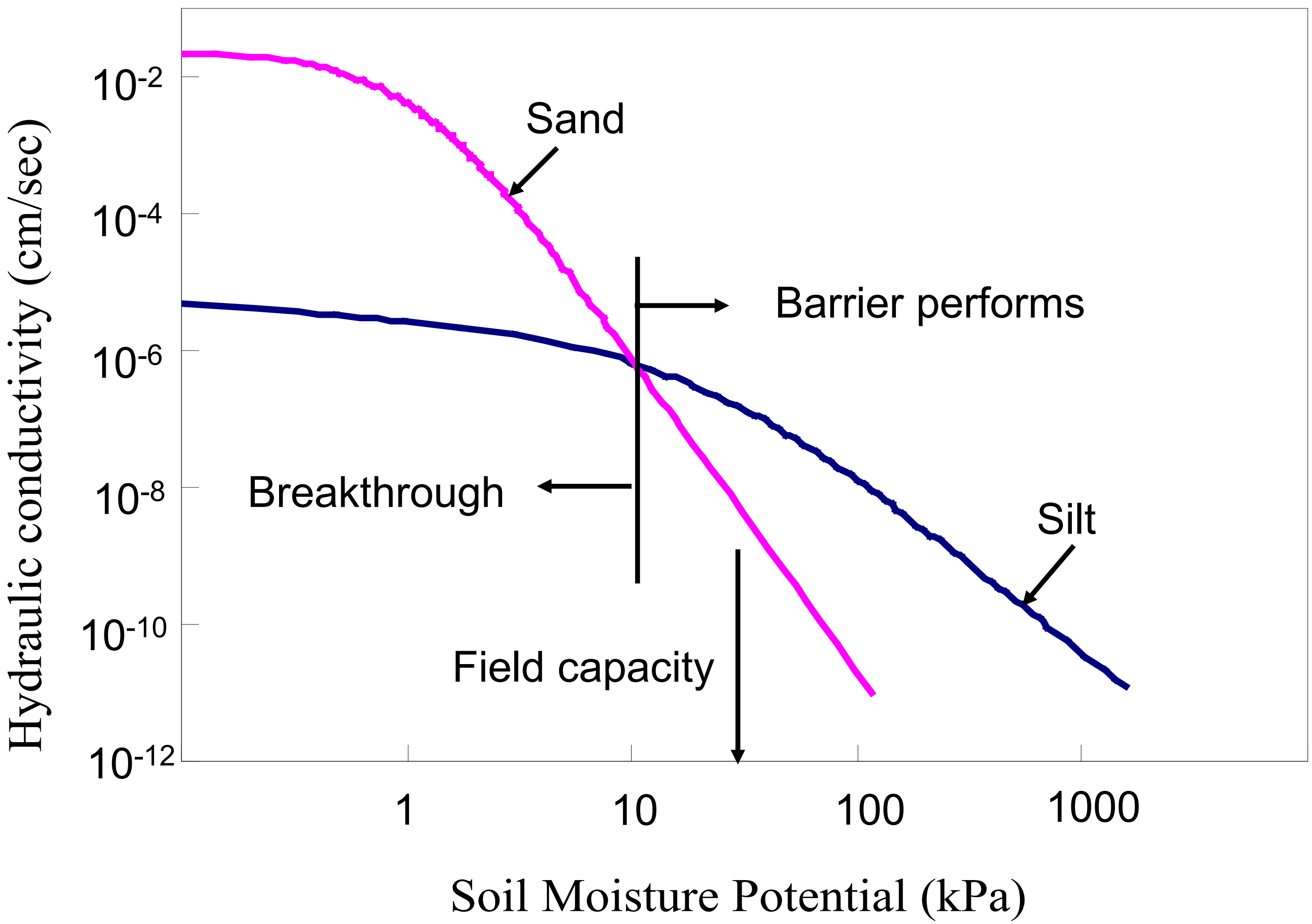
R = residual

S = saturated

α = 1 / AEP

n = slope

Capillary barrier function



Model input: boundary conditions and internal sinks

- Represent environmental stress (boundary conditions and internal sinks) to the soil profile (modeled domain)
- Atmospheric data
- Plant community data

Atmospheric data

- Precipitation
- Potential evapotranspiration (PET)
  - Describes the ability of the atmosphere to remove water from the soil profile
- Type of data
  - Average
  - 10-yr
  - Period of record
  - Wettest 10 years on record
  - Average all Jan. 1 data, Jan. 2 data, etc
- Requires multiple years to assure equilibrium

Plant parameters

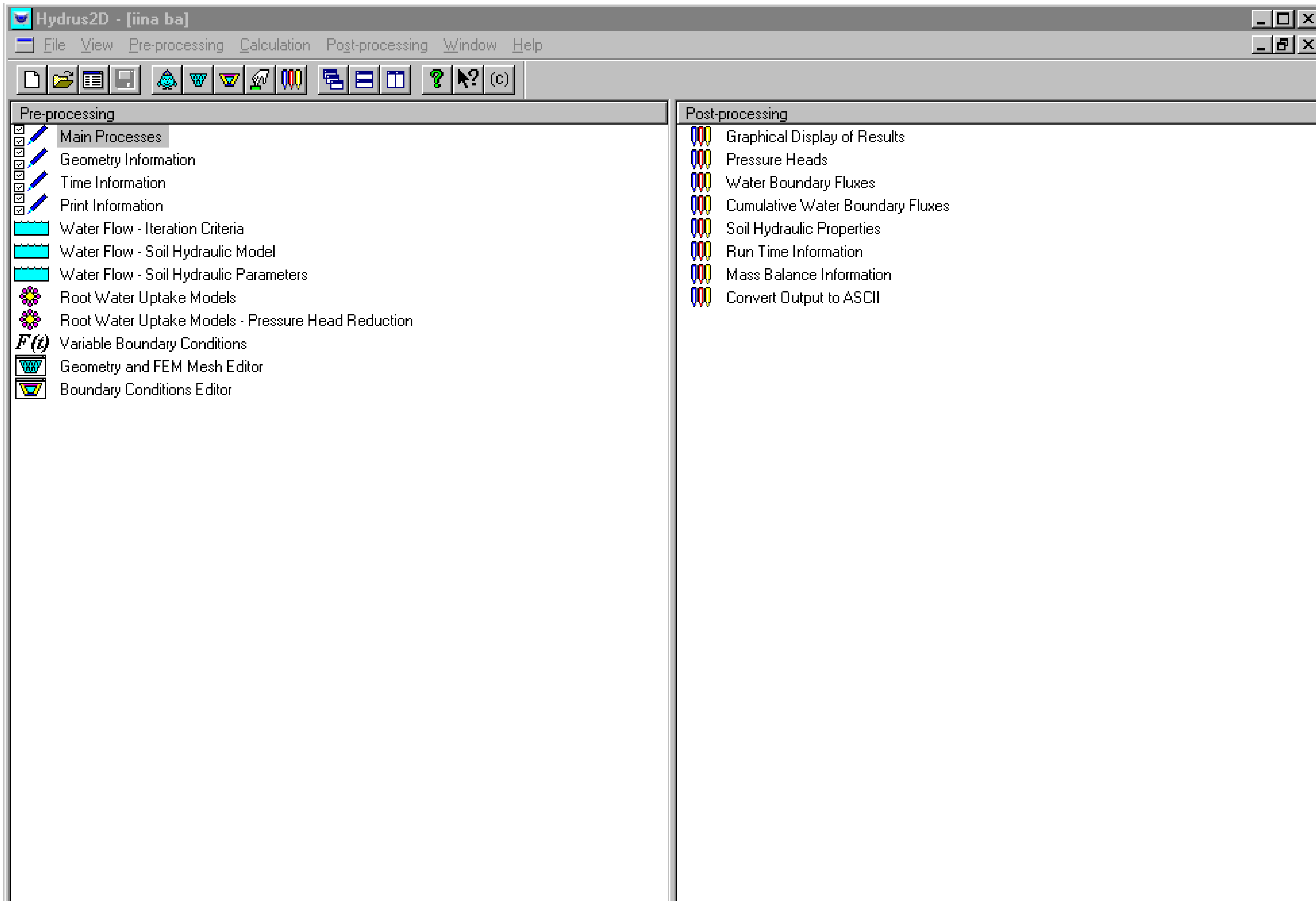
- Ideal plant community is active year-round and roots throughout the cover
- Factors
  - Transpiration rate (internal sink)
  - Cool/warm season (time-varying boundary condition)
  - Rooting depth (location of the internal sink)
  - Sensitivity to landfill gas
  - Nutrients
- Regulatory concern: source of data

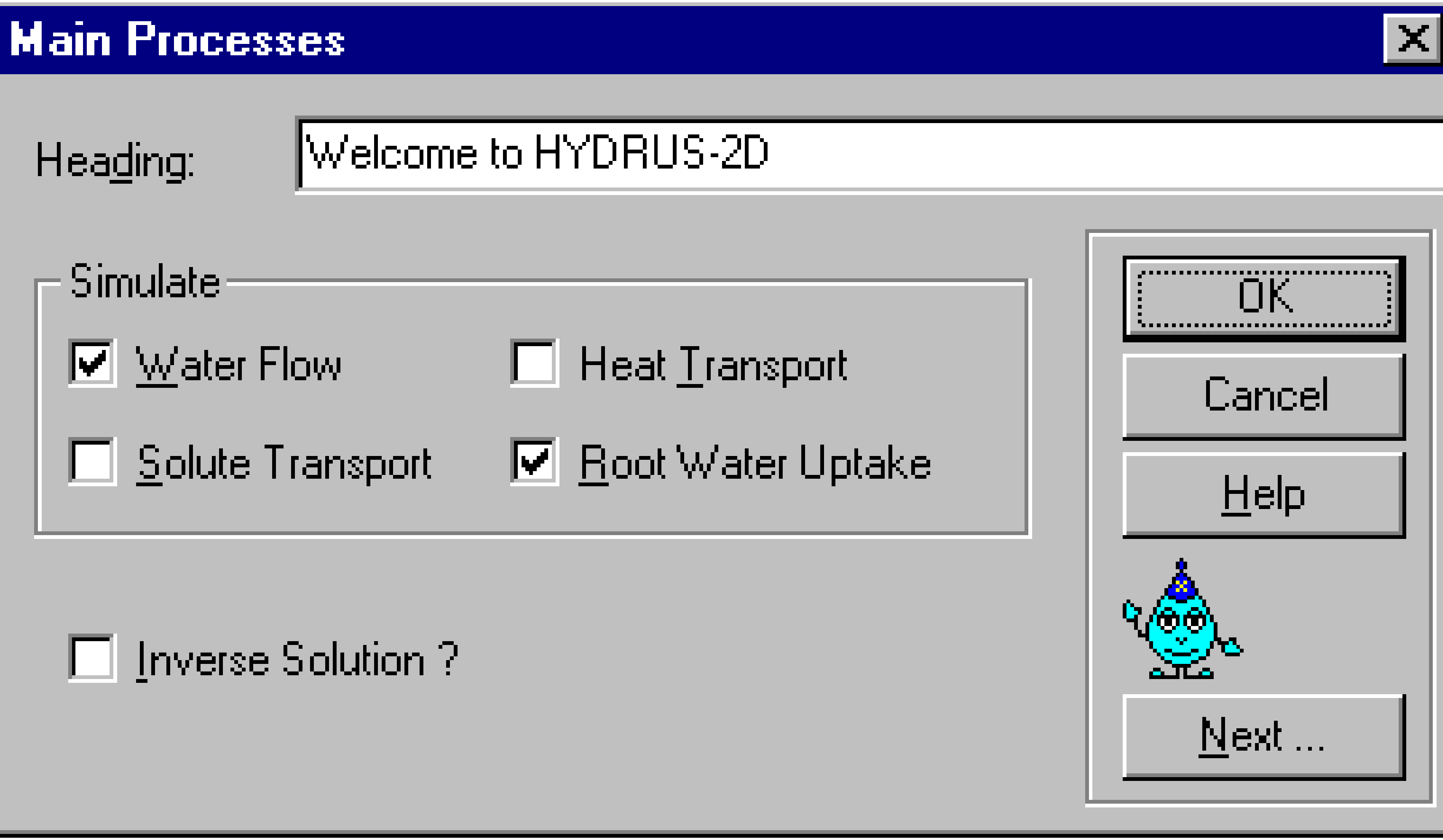
Plant community data

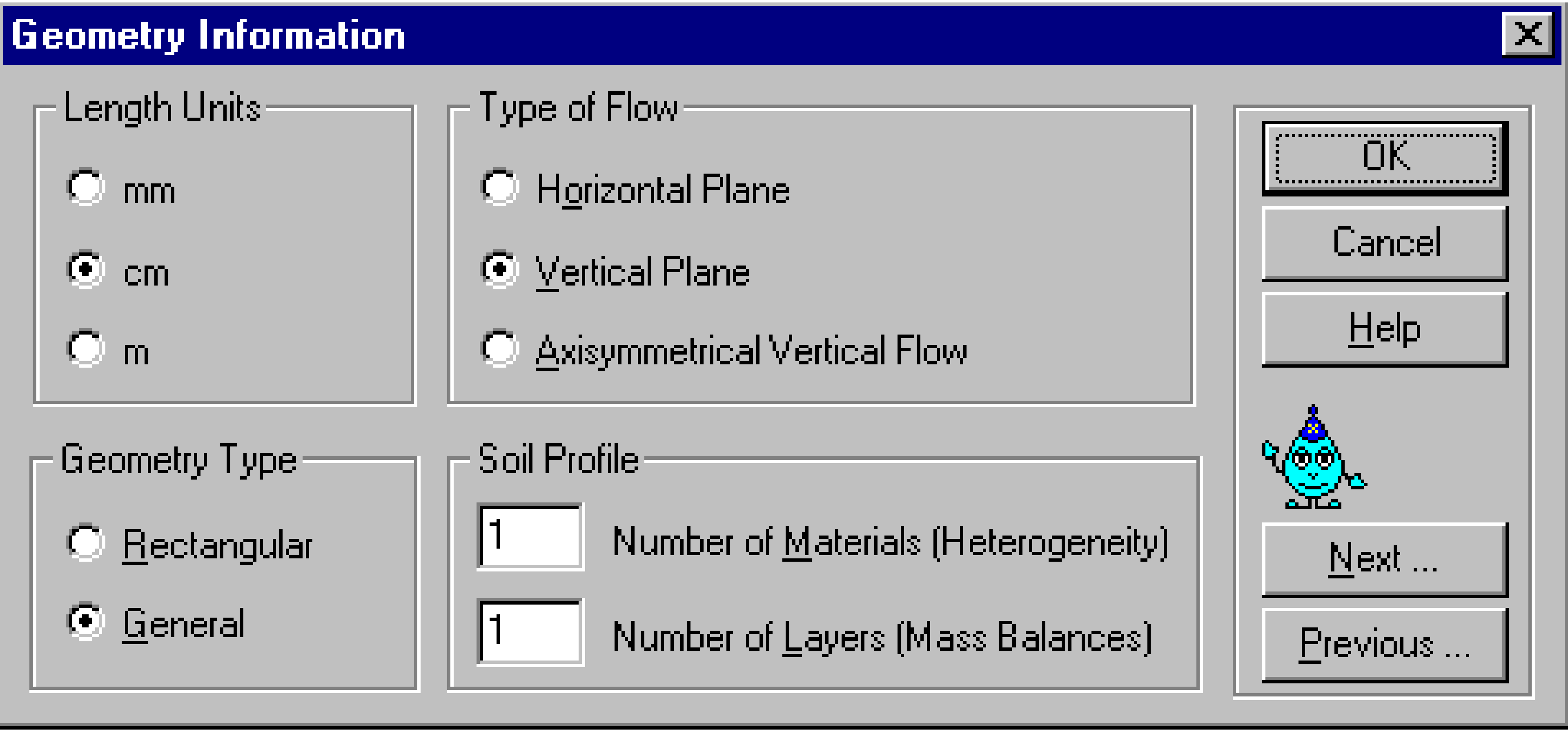
- Need for modeling
  - Location of roots in soil profile
  - Partitioning of PET into PE and PT
  - Seasonal timing
- Available data
  - Rooting depth
  - Leaf area index
  - Dates of freezing temperatures

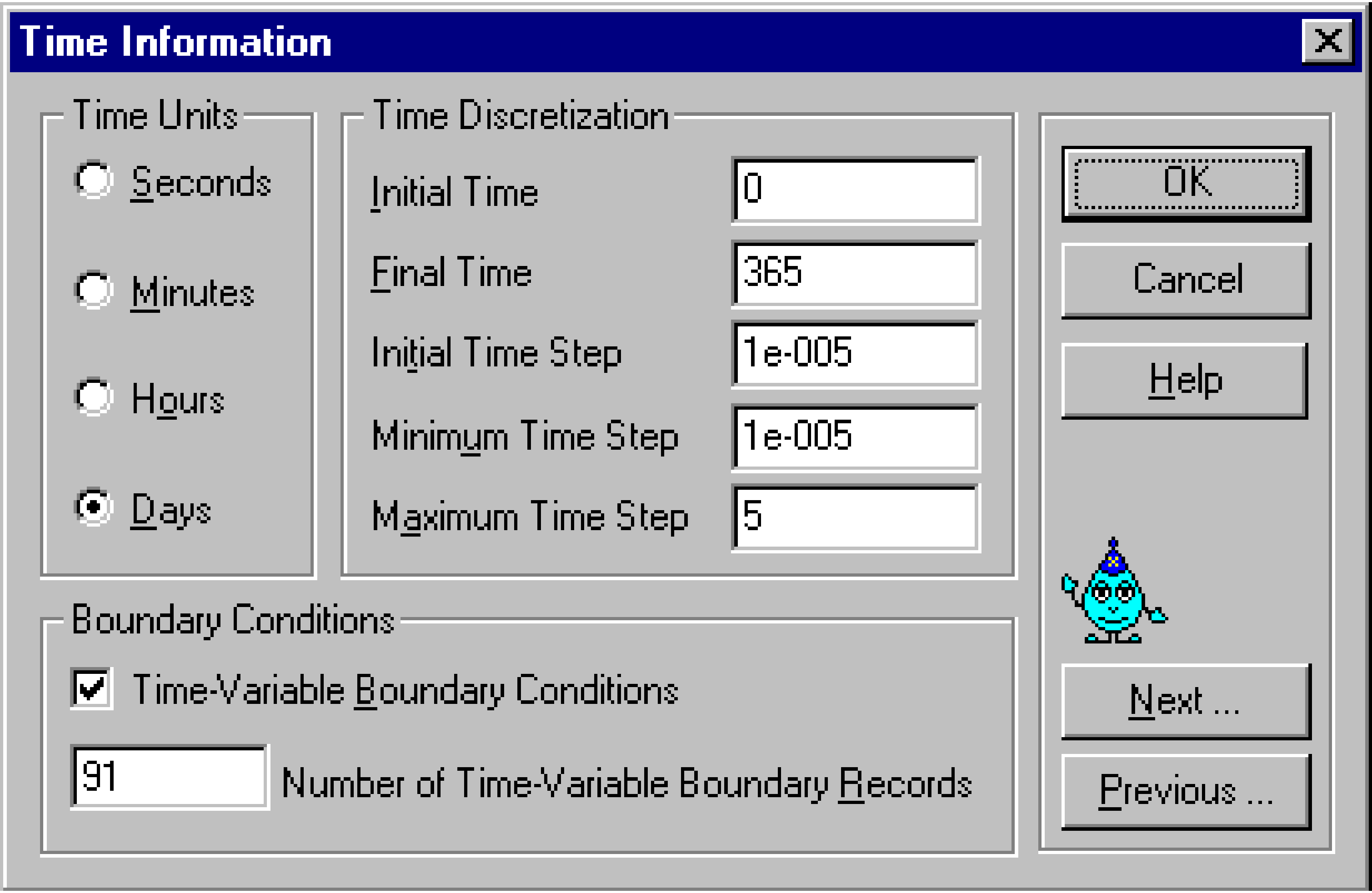
Modeling and vadose zone parameters Regulatory take-home message

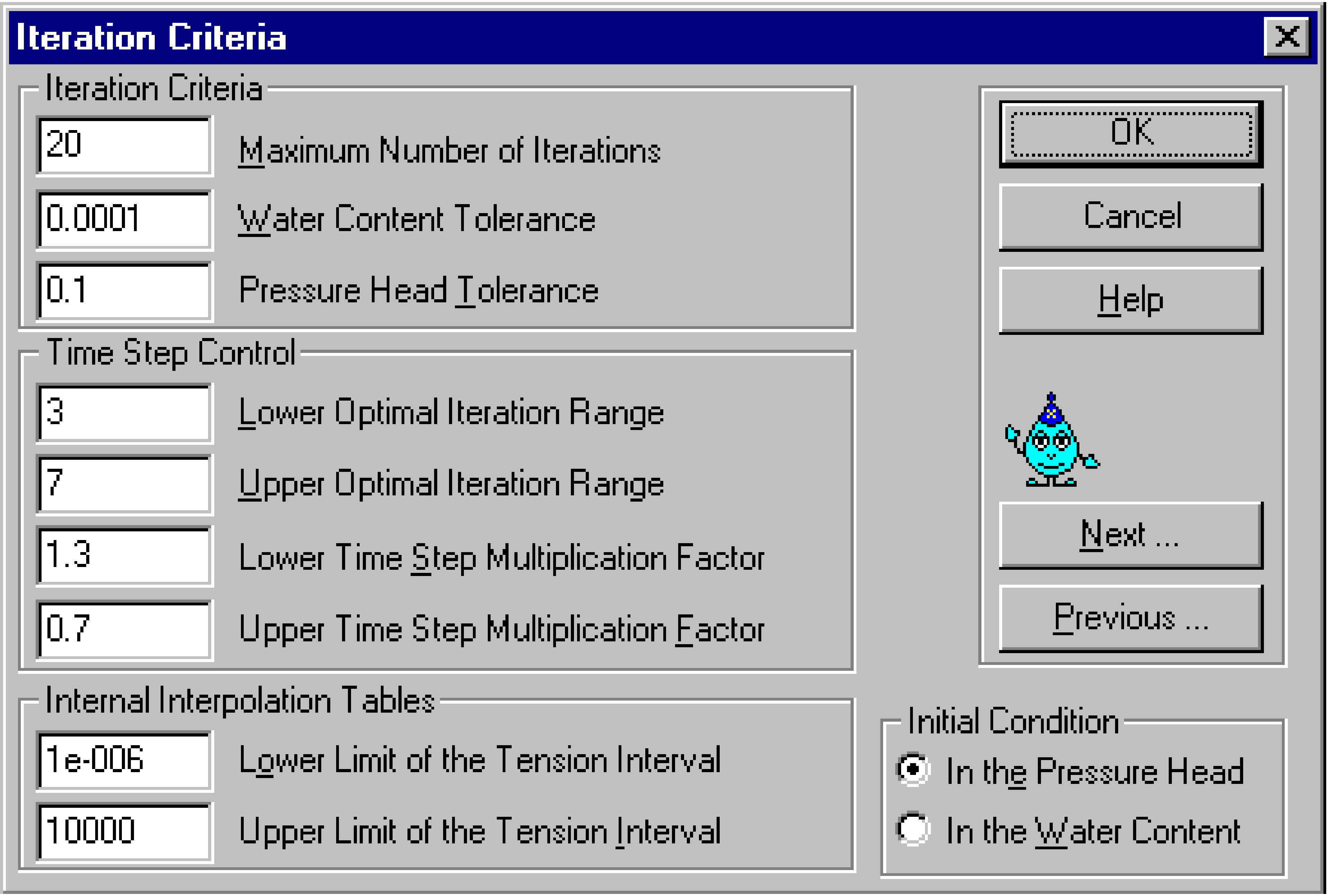
- Understand origin of vadose zone parameters: soil-specific parameters derived from lab measurements required for modeling
- Retention curve and K_{sat} *MUST* be determined by analysis of specific soil
- Describing soil *type* and then using typical vadose zone values for that *type* is not OK
- Plant data are difficult to obtain
- Design engineer / regulatory analyst interaction - agree *prior* to modeling

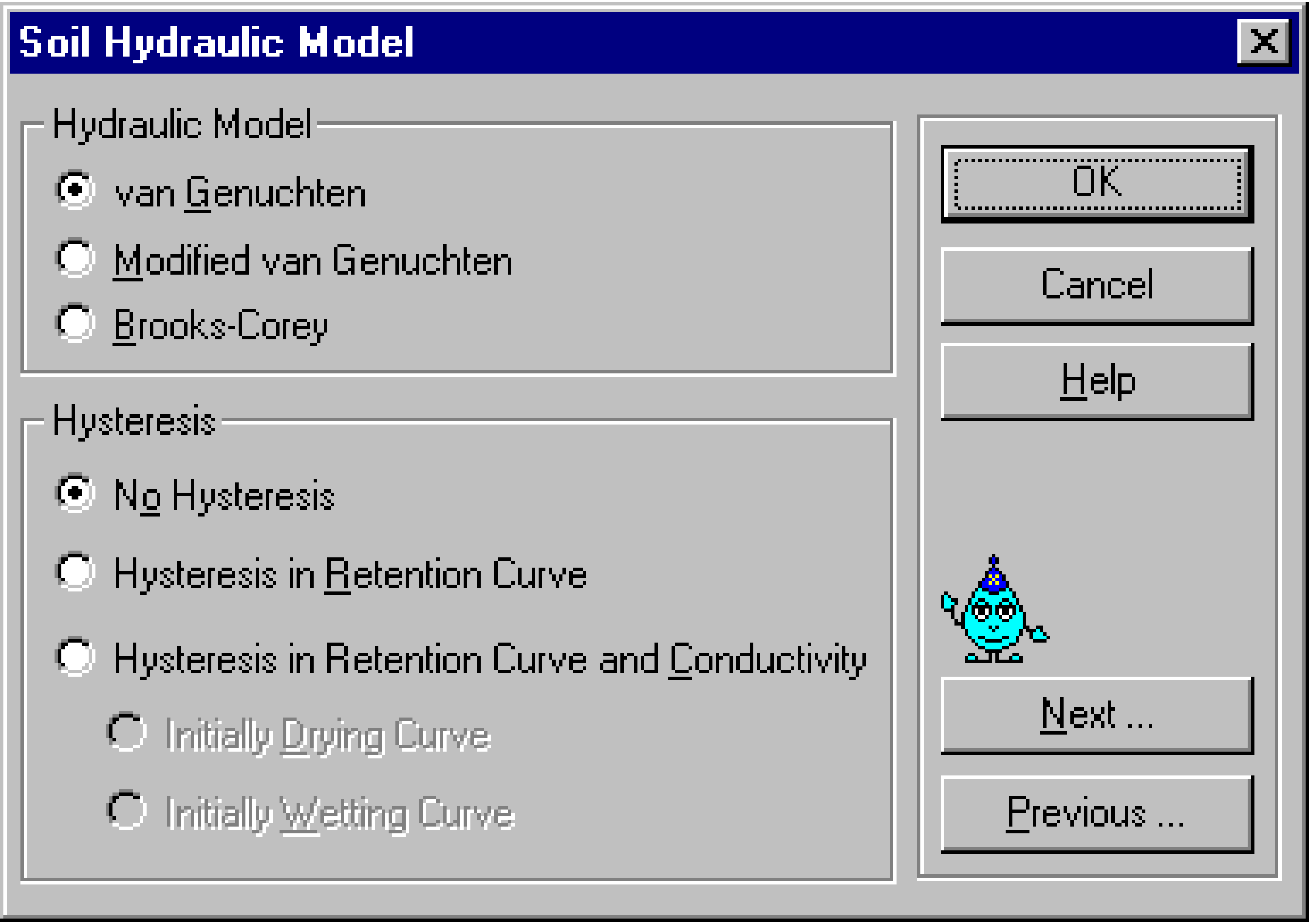

Hydrus2D - [iina ba]
File View Pre-processing Calculation Post-processing Window Help
Pre-processing
Main Processes
Geometry Information
Time Information
Print Information
Water Flow - Iteration Criteria
Water Flow - Soil Hydraulic Model
Water Flow - Soil Hydraulic Parameters
Root Water Uptake Models
Root Water Uptake Models - Pressure Head Reduction
F(t) Variable Boundary Conditions
Geometry and FEM Mesh Editor
Boundary Conditions Editor
Post-processing
Graphical Display of Results
Pressure Heads
Water Boundary Fluxes
Cumulative Water Boundary Fluxes
Soil Hydraulic Properties
Run Time Information
Mass Balance Information
Convert Output to ASCII


Main Processes
Heading:
Welcome to HYDRUS-2D
Simulate
Water Flow
Heat Transport
Solute Transport
Root Water Uptake
Inverse Solution ?
OK
Cancel
Help
Next ...


Geometry Information
Length Units
mm
cm
m
Type of Flow
Horizontal Plane
Vertical Plane
Axisymmetrical Vertical Flow
OK
Cancel
Help
Geometry Type
Rectangular
General
Soil Profile
1
Number of Materials (Heterogeneity)
1
Number of Layers (Mass Balances)
Next ...
Previous ...


Time Information
Time Units
Seconds
Minutes
Hours
Days
Time Discretization
Initial Time
0
Final Time
365
Initial Time Step
1e-005
Minimum Time Step
1e-005
Maximum Time Step
5
OK
Cancel
Help
Next ...
Previous ...
Boundary Conditions
Time-Variable Boundary Conditions
91
Number of Time-Variable Boundary Records


Iteration Criteria
Iteration Criteria
20
Maximum Number of Iterations
0.0001
Water Content Tolerance
0.1
Pressure Head Tolerance
Time Step Control
3
Lower Optimal Iteration Range
7
Upper Optimal Iteration Range
1.3
Lower Time Step Multiplication Factor
0.7
Upper Time Step Multiplication Factor
Internal Interpolation Tables
1e-006
Lower Limit of the Tension Interval
10000
Upper Limit of the Tension Interval
OK
Cancel
Help
Next ...
Previous ...
Initial Condition
In the Pressure Head
In the Water Content



Soil Hydraulic Model
Hydraulic Model
van Genuchten
Modified van Genuchten
Brooks-Corey
Hysteresis
No Hysteresis
Hysteresis in Retention Curve
Hysteresis in Retention Curve and Conductivity
Initially Drying Curve
Initially Wetting Curve
OK
Cancel
Help
Next ...
Previous ...

Water Flow Parameters

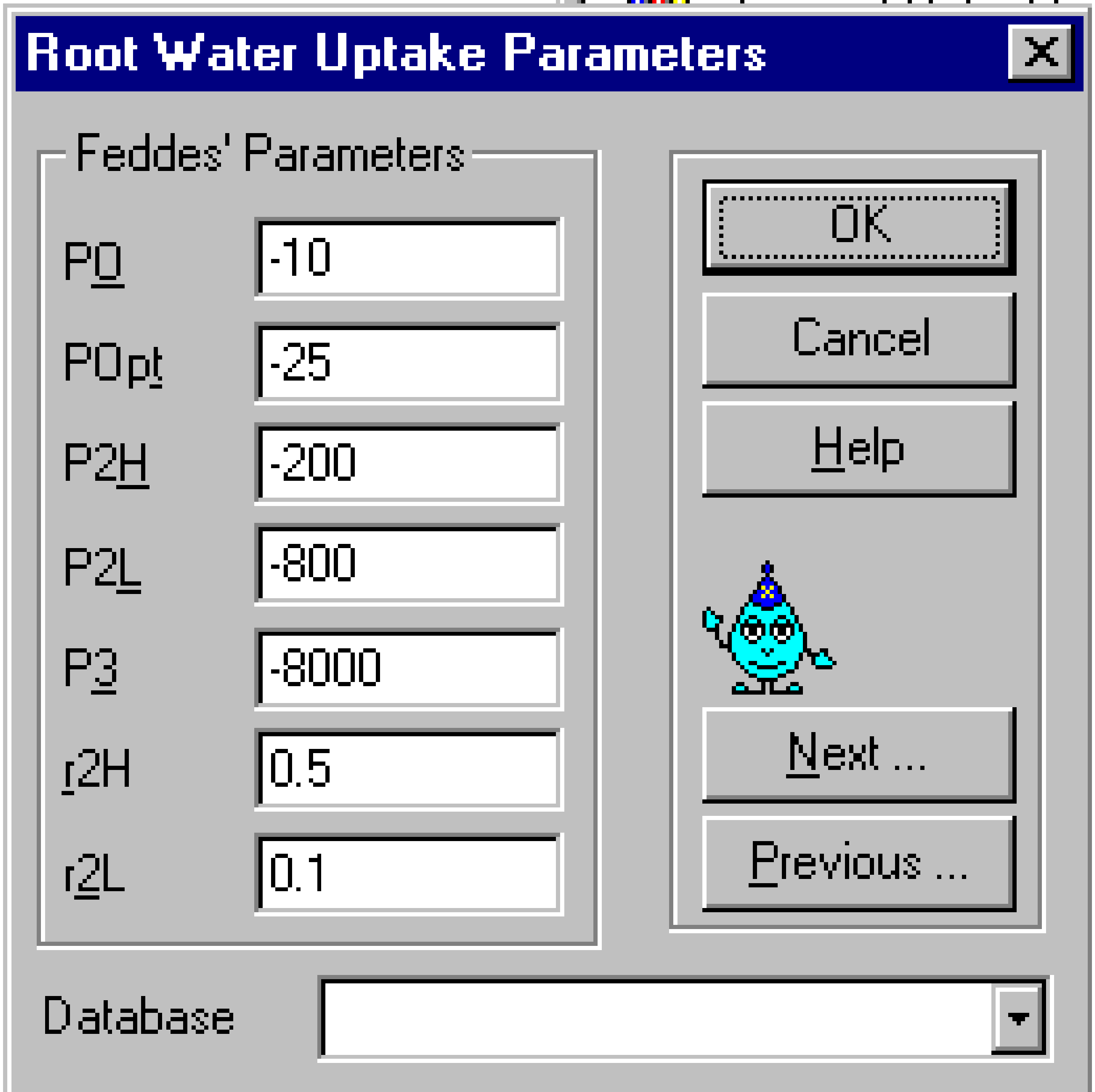
	Qr	Qs	Alpha	n	Ks	l
1	0.12	0.41	0.299	1.69	23.33	0.5

Soil Catalog

Neural Network Prediction

Temperature Dependence

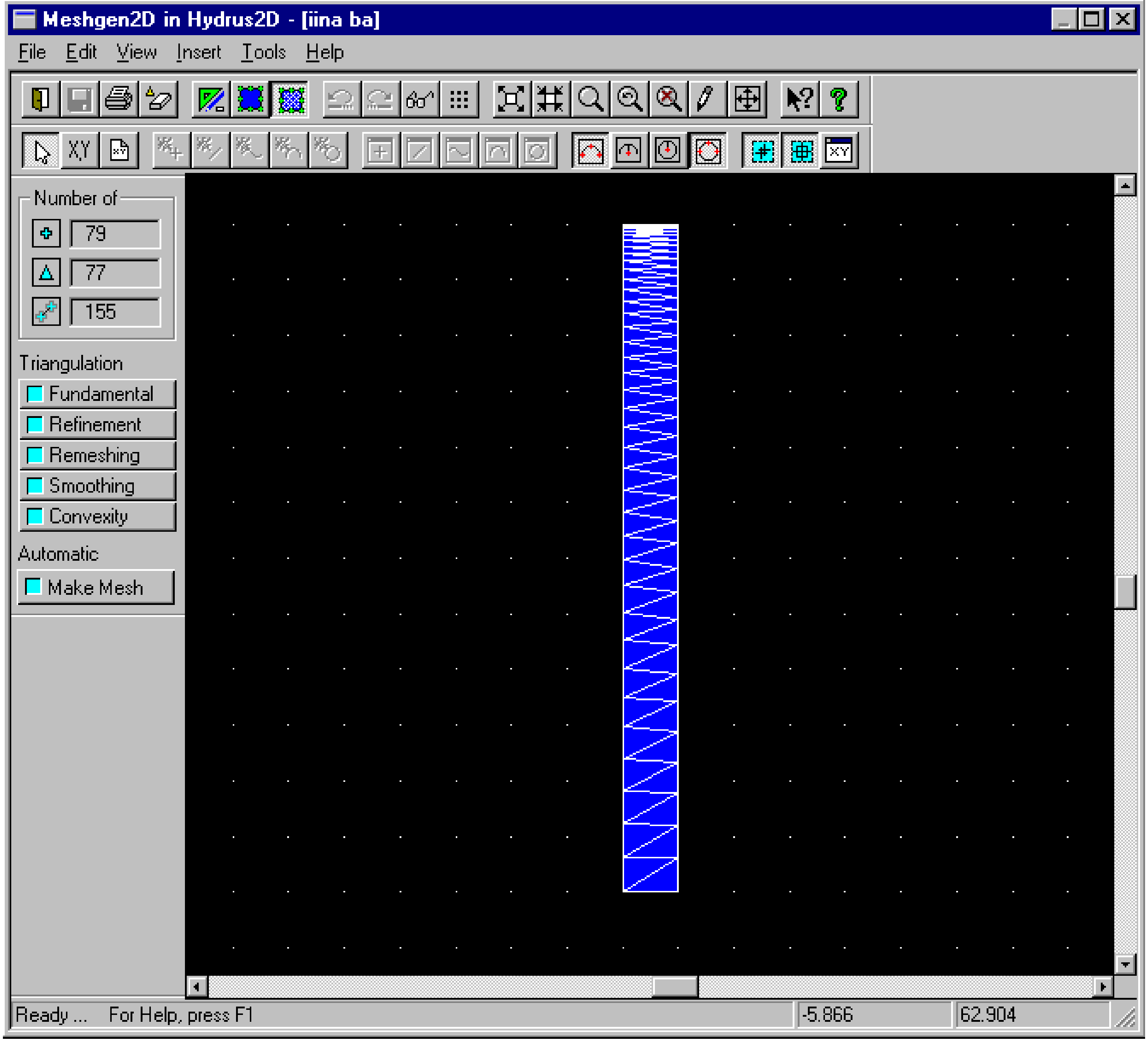
OK Cancel Help Next ... Previous ...

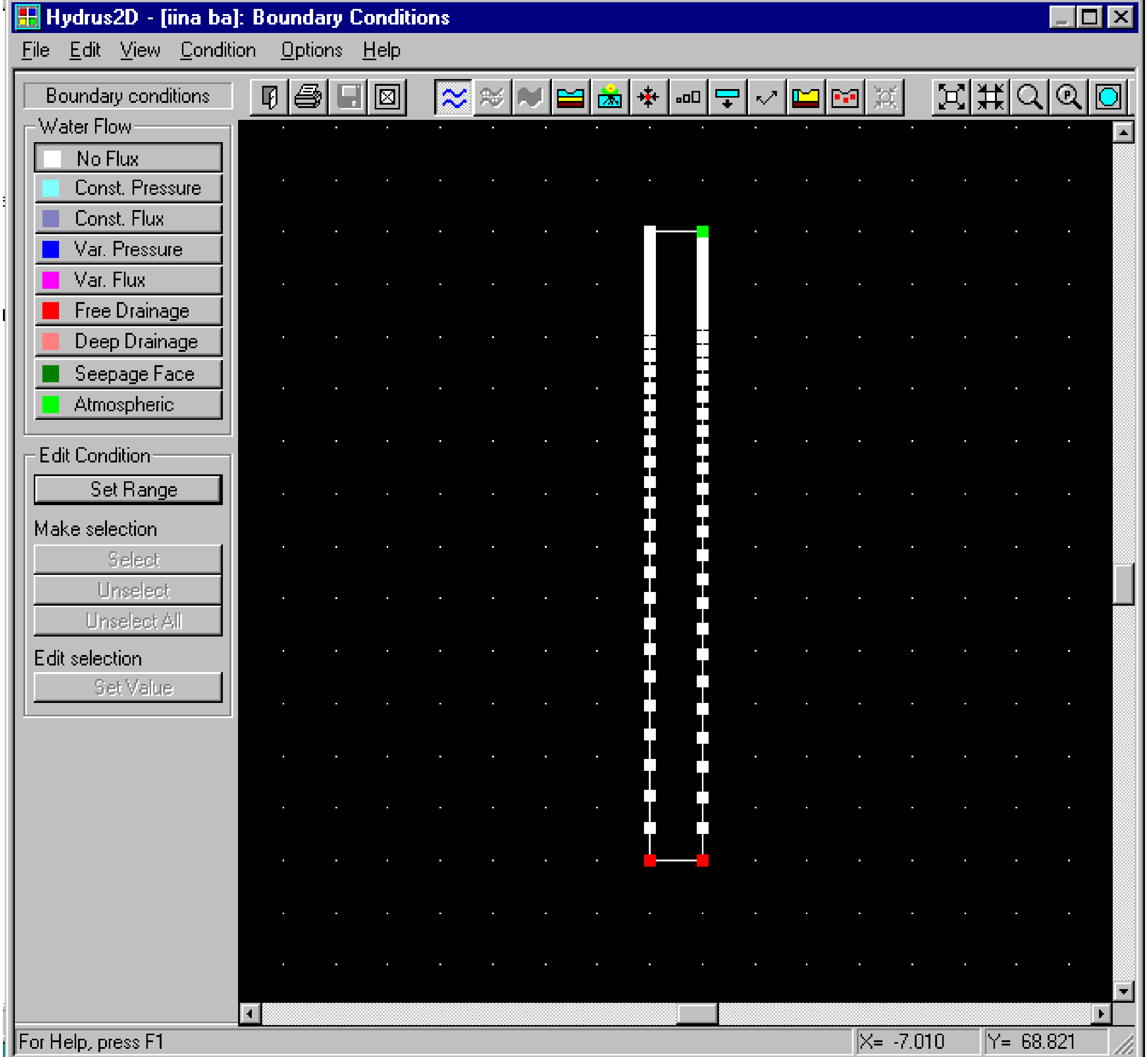

Root Water Uptake Parameters
Feddes' Parameters
P0 -10
POpt -25
P2H -200
P2L -800
P3 -8000
r2H 0.5
r2L 0.1
OK
Cancel
Help
Next ...
Previous ...
Database

Time Variable Boundary Conditions

	Time	Precip.	Evap.	Transp.	hCritA	rGWL	GWL
1	5	0	0.173	0	20000	0	0
2	6	0.7112	0.173	0	20000	0	0
3	11	0	0.173	0	20000	0	0
4	12	0.0762	0.173	0	20000	0	0
5	26	0	0.173	0	20000	0	0
6	27	0.0762	0.173	0	20000	0	0
7	32	0	0.173	0	20000	0	0
8	33	0	0.274	0	20000	0	0
9	34	0.0508	0.274	0	20000	0	0
10	55	0	0.274	0	20000	0	0
11	56	0.762	0.274	0	20000	0	0
12	60	0	0.274	0	20000	0	0

OK | Cancel | Help | Add Line | Delete Line | Next ... | Previous ...


Meshgen2D in Hydrus2D - [iina ba]
File Edit View Insert Tools Help
XY
Number of
79
77
155
Triangulation
Fundamental
Refinement
Remeshing
Smoothing
Convexity
Automatic
Make Mesh
Ready ... For Help, press F1
-5.866
62.904


Hydrus2D - [iina ba]: Boundary Conditions
File Edit View Condition Options Help
Boundary conditions
Water Flow
No Flux
Const. Pressure
Const. Flux
Var. Pressure
Var. Flux
Free Drainage
Deep Drainage
Seepage Face
Atmospheric
Edit Condition
Set Range
Make selection
Select
Unselect
Unselect All
Edit selection
Set Value
For Help, press F1
X= -7.010
Y= 68.821

ACAP

- Nationwide network of field-scale cover testing facilities
- Provides measurement (not estimate) of performance
- Side-by-side comparison of alternative with prescriptive
- Additional instrumentation to provide data for improved understanding of mechanisms and numerical estimation methods

Other monitoring methods

- Soil moisture data can be used to *estimate* performance
  - Qualitative: did a wetting front progress to depth?
  - Quantitative:Darcy's Law calculations
- These methods have problems
  - Qualitative methods rely on incorrect assumptions
  - Measurement error can lead to order-of-magnitude variation in Darcy's Law methods
- Correlating these instrument data with a single point of measurement would help

Qualitative use of instrument data to describe flux through cover (1)

- Statement: "The bottom probe(s) did not show any increase in moisture content, therefore the wetting front did not reach that depth and no flux occurred."
- Issue: If the soil at the bottom probe is at constant moisture content (and probably at unit gradient), then the soil is draining at that unsaturated hydraulic conductivity

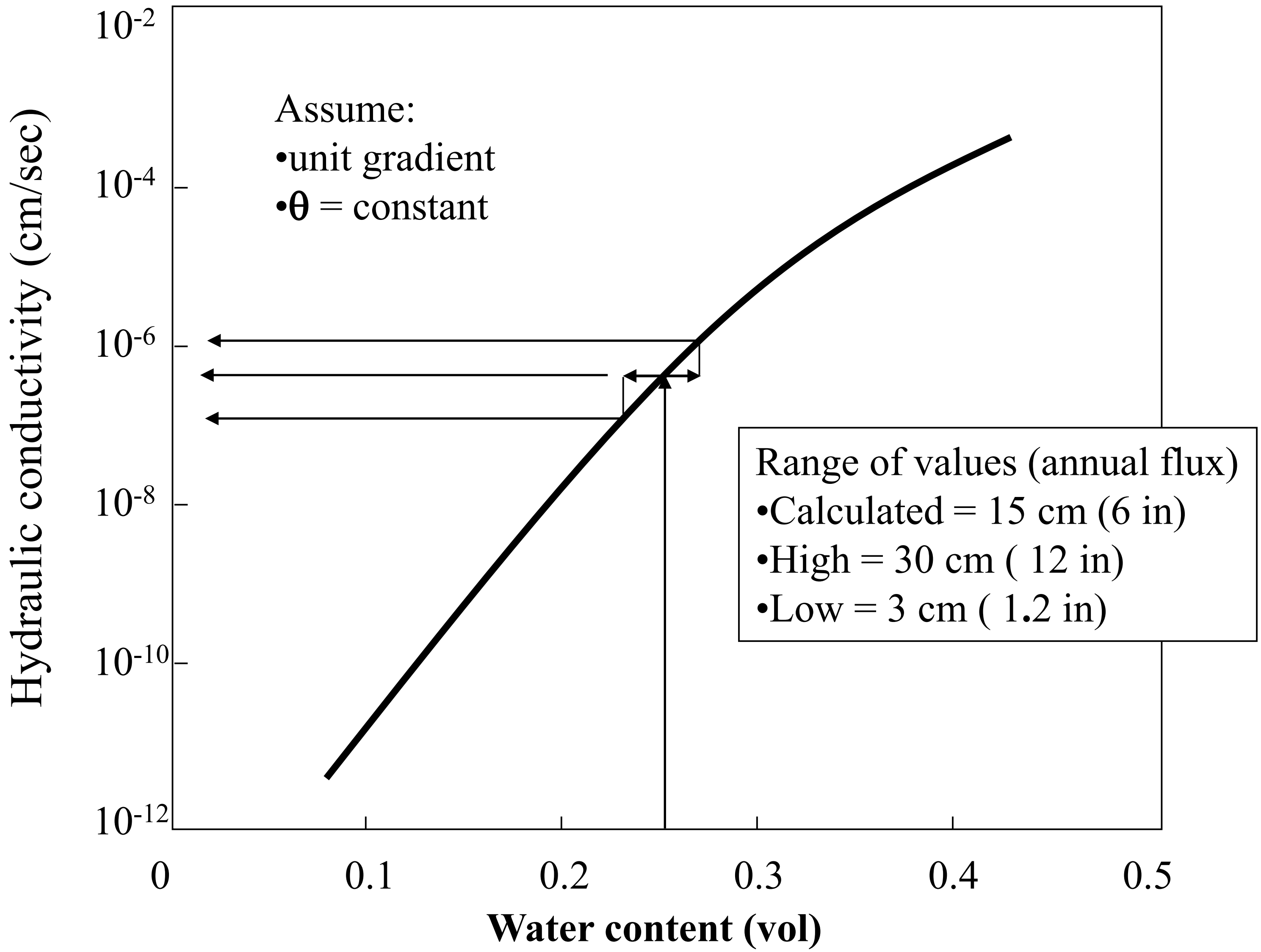
Qualitative use of instrument data to describe flux through cover (2)

- Statement: “The bottom probe(s) did show any increase in moisture content, therefore the wetting front did reach that depth and flux did occurred.”
- Issue: Even if the soil at the bottom probe shows an increase in moisture content, it may not reach the level required to drain significant water (particularly if a capillary barrier is present)

Darcy's Law calculations from soil instrument data

- A simple method to estimated flux:
  - Assume unit gradient conditions (not a bad assumption at depth)
  - Assume instrument data is *very* accurate
  - Flux = unsaturated hydraulic conductivity
- Issues:
  - In unsaturated conditions hydraulic conductivity is highly sensitive to moisture content
  - Small errors in measurement can translate to order-of-magnitude errors in flux estimates

Methodology and range of calculated values for instrumented (Darcy's Law calculations) estimates of cover performance



Improved monitoring methods

- ACAP-style lysimeter is probably excessive for permitting activities
- Instrumentation alone offers significant possibility of error
- Hybrid system may be considered
  - Small lysimeter
  - Some instrumentation
  - *Measurement* at one point can verify additional instrumented locations